



National Aeronautics and Space Administration

UAS Integration in the NAS Project

An Evaluation of Detect and Avoid Displays for UAS: The Effect of Information Level and Display Location on Pilot Performance

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Air Force Research Laboratory



- UAS in the NAS Project
 - Developed to help address technical barriers to integration of unmanned aircraft systems (UAS) into the national airspace system (NAS)
 - Findings help guide development of RTCA Special Committee 228's Minimum Operational Performance Standards (MOPS) for UAS
 - An outstanding technical barrier is providing UAS pilots with a means to “detect and avoid” other aircraft
 - Means of compliance with 14CFR, Section 91.113 - pilots must remain *well clear* from other aircraft through “see and avoid”
- Detect and Avoid (DAA) System
 - A collection of technologies - consisting of both hardware & software – that can provide pilots with the necessary information to self-separate from other aircraft
 - A traffic display would serve as substitute for manned pilots' ability to see outside their aircraft
 - Critical question: what are the display requirements for such a system?

- DAA Display Research
 - Several part-task studies have looked UAS traffic display
 - Friedman-Berg et al. (2014) & Draper et al. (2014) focused on identifying the minimum information requirements
 - Results were largely in agreement, most significant difference being the inclusion of maneuver recommendations (display guidance) in Draper et al.
 - Bell (2012) found that “advanced” displays – i.e., those that provided a level of display guidance – led to less severe separation violations than displays without guidance

Intruder Information	Friedman-Berg et al. (2014)	Draper et al. (2014)	Bell (2012)
Aircraft ID	✓	✓	
Intruder Position & Direction	✓	✓	✓
Range	✓	✓	✓
Bearing	✓	✓	✓
Altitude	✓	✓	✓
Alert Level/Threat Status	✓	✓	✓
Vertical & Horizontal Trend	✓		
Display Guidance		✓	✓

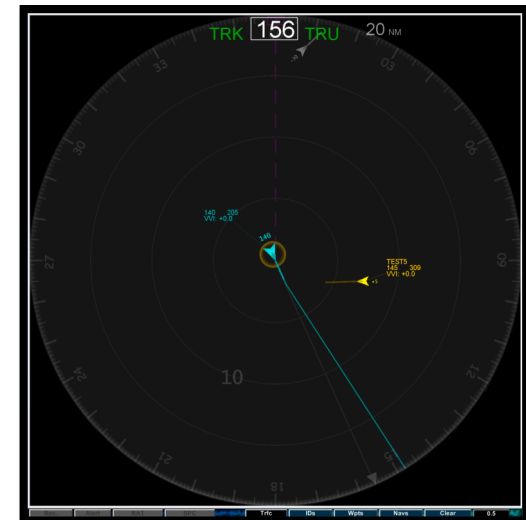


- Current Study:
 - Continues examination of DAA display requirements within a “full mission” task environment
 - Tests different information levels (no guidance vs. guidance) and location of the traffic information
 - Standalone (i.e., bootstrap) displays may be easier to develop, but may hinder performance relative to displays integrated into command and control interface
 - Focus on the displays’ impact on pilots’ measured response (MR)
 - MR can be understood as the quantification of the end-to-end response time for a UAS pilot to complete a self separation maneuver in response to a DAA display alert
 - Measured response metrics can reveal the amount of time pilots spent interacting with different displays, allowing direct comparisons
 - Longer MR times may result in delayed maneuvering, which can in turn increase likelihood of a separation violation
 - MR times can also inform human response models that are used in fast-time simulation and the alerting threshold parameters used by the alerting logic

- Participants
 - 12 active UAS pilots (M = 39 years of age)
 - All had military UAS experience (avg. 216 hrs)
 - 8/12 had civil UAS experience (avg. 60 hrs)
- Simulation Environment
 - Ground Control Station
 - Vigilant Spirit Control Station (VSCS; right)
 - Provided command and control interfaces, aircraft information, and a simulated out-the-window view, across 3 monitors
 - Displayed traffic information in select conditions
 - Mouse and keyboard inputs only
 - Cockpit Situation Display (CSD; right)
 - Standalone CDTI only active in select conditions
 - One monitor, directly to left of VSCS monitors








Vigilant Spirit Control Station



Cockpit Situation Display

- 2 x 2 Repeated Measures Experimental Design
 - *Information Level:*
 - Basic Information
 - Standard intruder information (as set by Friedman-Berg et al., 2014)
 - » No display guidance
 - Multi-level alerting
 - Advanced Information
 - Standard intruder information
 - Multi-level alerting
 - » Included additional level
 - Suite of guidance tools
 - » Trial planning tools
 - » Recommended Maneuvers
 - *Display Location:*
 - Standalone Display
 - Information presented within CSD
 - Pilots still used VSCS to input changes to aircraft
 - Integrated Display
 - Information presented within VSCS command and control interface

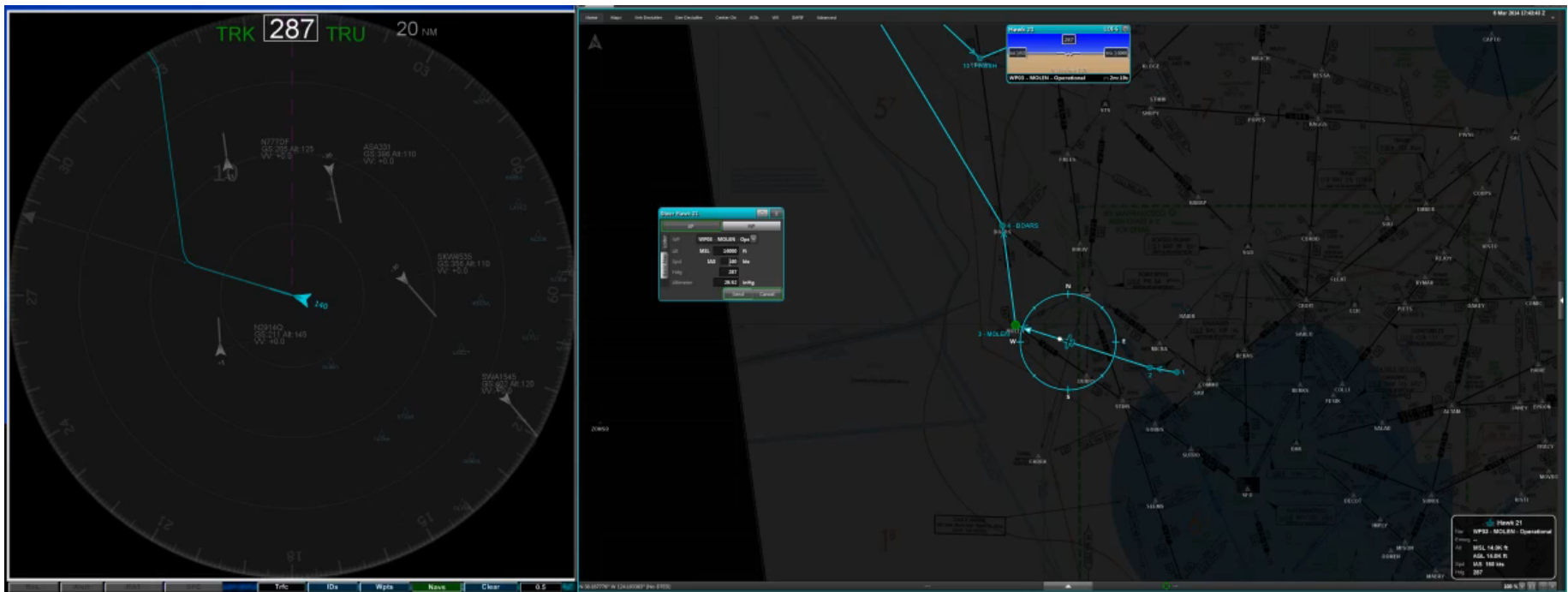
- Multi-Level Alerting
 - Visual and auditory alerts tied to predicted threat level of nearby traffic
 - Based on predicted closest point of approach (CPA) between ownship and intruder
 - Horizontal miss distance (HMD), vertical miss distance (ZTHR), and time to CPA criteria all had to be satisfied to be assigned given threat level
 - Pilots instructed to maneuver *prior* to collision avoidance alert being generated, which was their indication that separation had been lost

Alert/Threat Level	HMD	ZTHR	Time to CPA	Symbol
Proximal	> 2 NM	> 900 FT	N/A	
Preventative	< 2 NM	< 900 FT	< 120 secs	
Self Separation	< 1.2 NM	< 900 FT	< 110 secs	
Predicted CA Alert*	< 0.8 NM	< 400 FT	< 110 secs	
Collision Avoidance	< 0.8 NM	< 400 FT	< 40 secs	

**Only present in the Advanced Information display conditions*

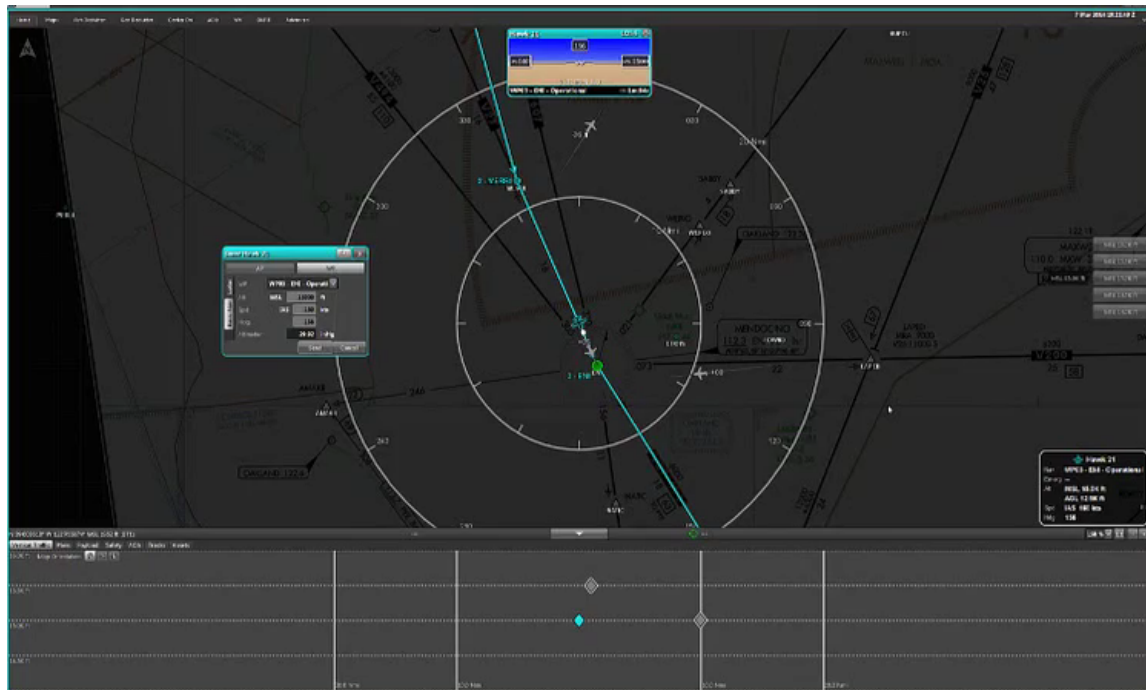
1. Basic Standalone Display

- Standard intruder information and multi-level alerting presented within CSD
 - No display guidance provided
 - VSCS served as command-and-control interface



4. Advanced Integrated Display

- Display guidance included, in addition to standard info and alerting
 - Trial planning tools allowed pilots to test different heading/altitude maneuvers before uploading
 - Maneuver recommendations offered suggested solutions





- Pilot Task
 - Operate simulated MQ-9 Reaper within civil airspace, under Instrument Flight Rules
 - Routes contained entirely within Class E, Oakland Center airspace
 - Instructed to coordinate maneuvers with ATC (over push-to-talk headset)
 - Missions lasted 40 minutes
 - Maintain well clear from nearby aircraft
 - 8 scripted encounters with the ownship (i.e., would lose separation absent of pilot intervention)
 - Additional tracks were included to emulate busy day at Oakland Center
 - Attend to secondary tasks
 - Respond to requests for status information (e.g., current fuel level)
 - Complete electronic checklists in response to system malfunctions

- Confederate Participants
 - Retired ATC managed all aircraft within experimental airspace
 - “Pseudo” pilots controlled simulated manned aircraft within airspace
- A researcher coordinated in real-time to ensure conflicts were generated



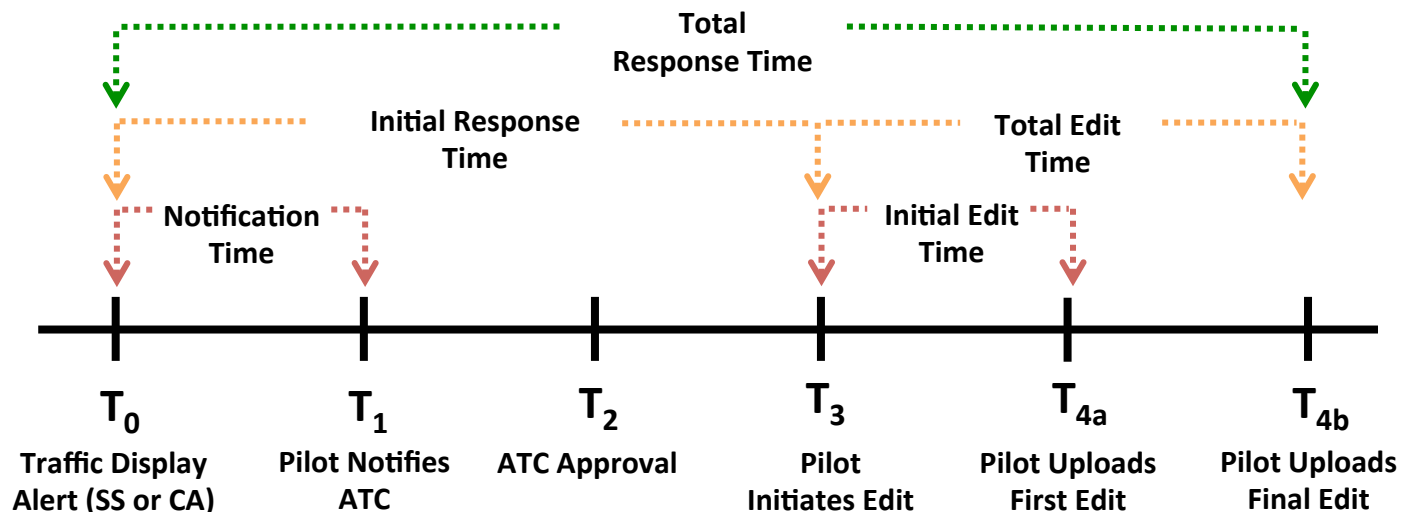
- Measured Response Metrics
 - A pilot-DAA interaction timeline was constructed, with emphasis on the pilots' interaction with ATC and the GCS (below)
 - The timestamps for each stage of the timeline were collected from a variety of sources:
 - GCS output files, DAA algorithm output files, voice recordings and logs, and video recordings

Stage	Description
T_0	DAA (self separation or collision avoidance) alert appears on the display
T_1	Pilot notifies ATC and requests a maneuver clearance
T_2	ATC provides maneuver clearance
T_3	Pilot initiates an edit in GCS to maneuver
T_{4a}	Pilot uploads 1st maneuver to aircraft
T_{4b}	Pilot uploads final maneuver to aircraft

- Measured Response Metrics

- From these timestamps, five metrics were extrapolated:

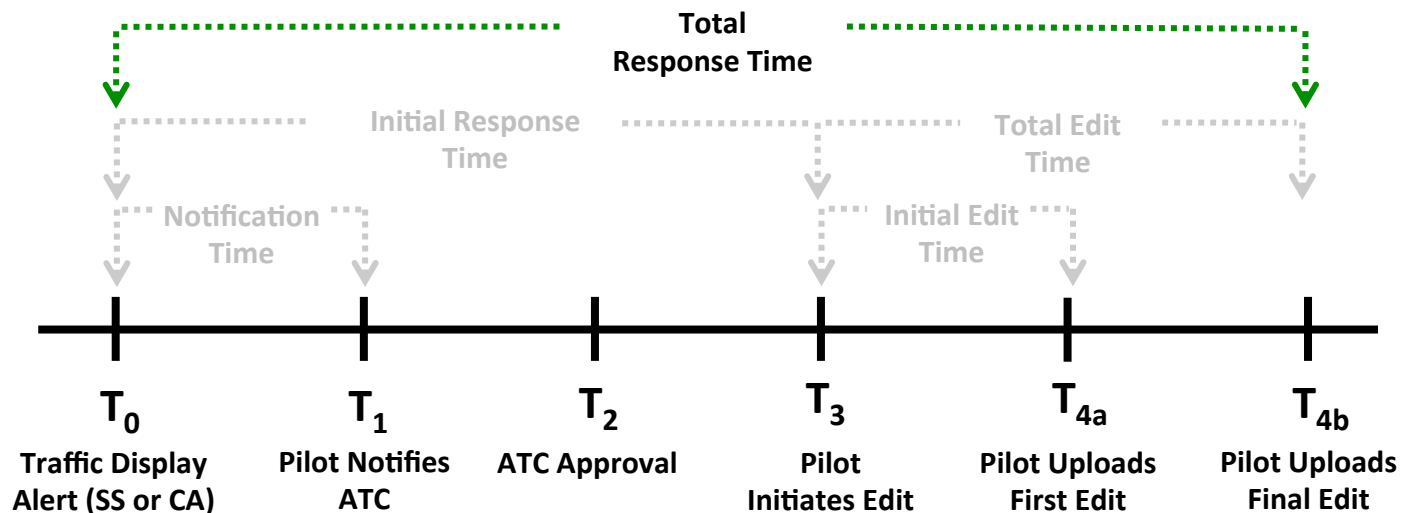
- Total Response Time* ($T_{4b} - T_0$) – how long it took the pilot to upload an appropriate maneuver following a DAA alert
- Initial Response Time* ($T_3 - T_0$) – how long it took the pilot to initiate an edit in the GCS
- Total Edit Time* ($T_{4b} - T_3$) – how long it took the pilot to implement appropriate maneuver
 - Initial Edit Time* ($T_{4a} - T_3$) – how long it took the pilot to implement an initial maneuver
- Notification Time* ($T_1 - T_0$) – how long it took the pilot to notify ATC following an alert



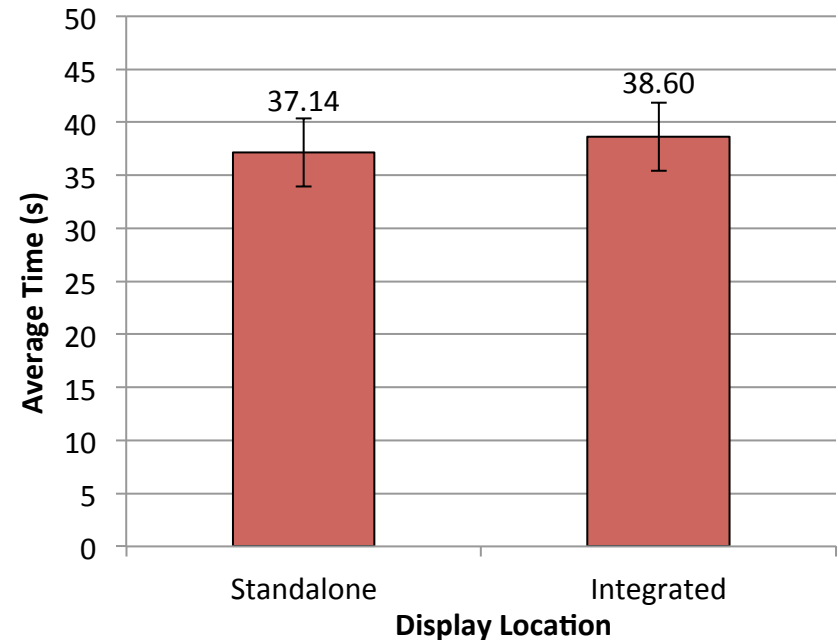
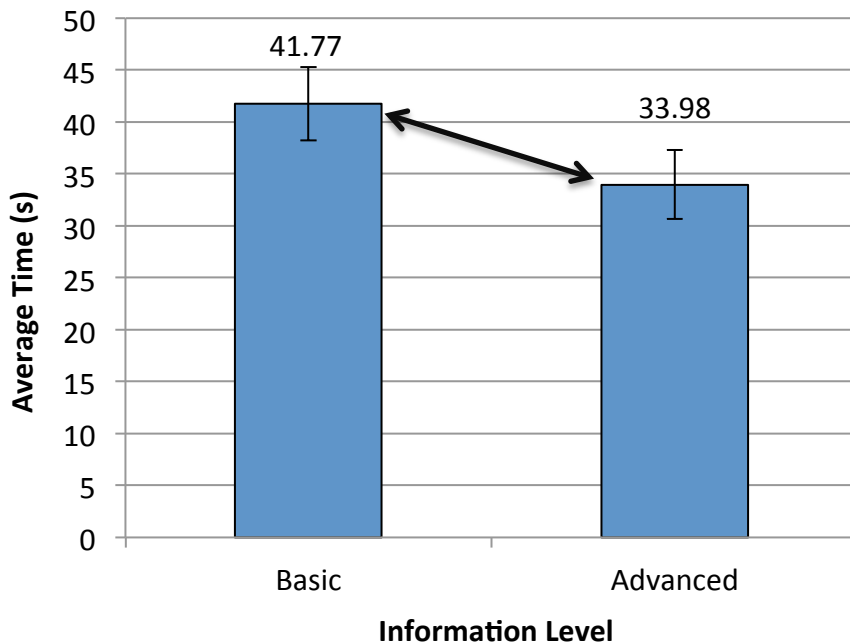
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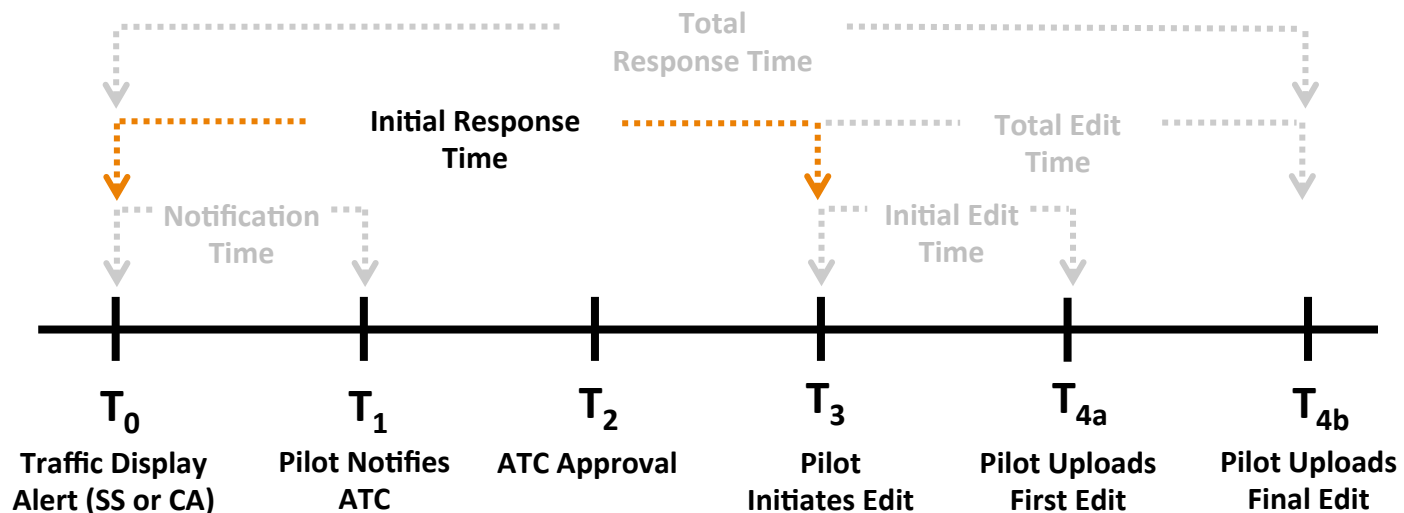
- Total Response Time
 - Significant main effect of Information Level on Total Response Times ($p < .05$)
 - Pilots took an average of **37.87s** to complete their final edit in response to SS/CA alerts (from first alert appearance)
 - Pilots **8s** faster (19%) on average in Advanced than Basic conditions
 - No other significant main effects or interaction



- Measured Response Metrics

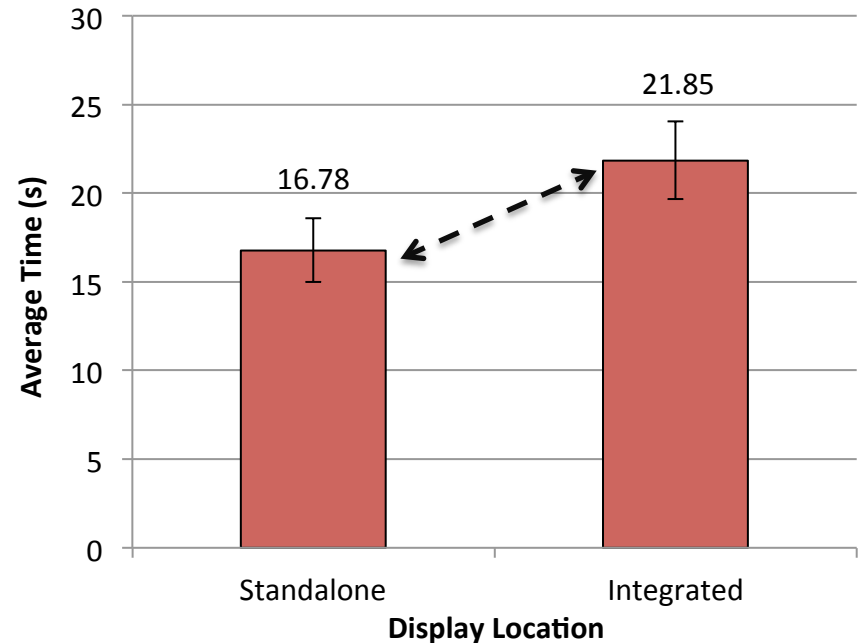
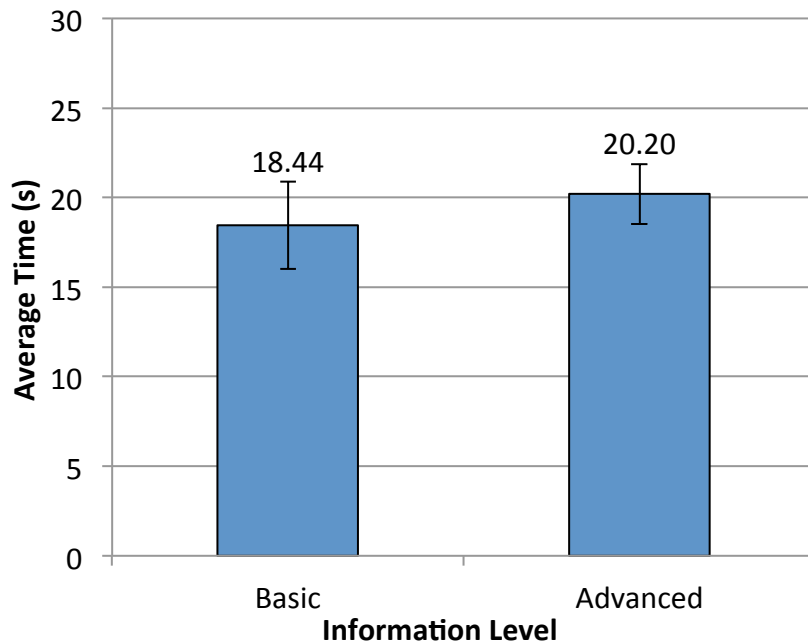
- From these timestamps, five metrics were extrapolated:

- Total Response Time* ($T_{4b} - T_0$) – how long it took the pilot to upload an appropriate maneuver following a DAA alert
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- Initial Response Time

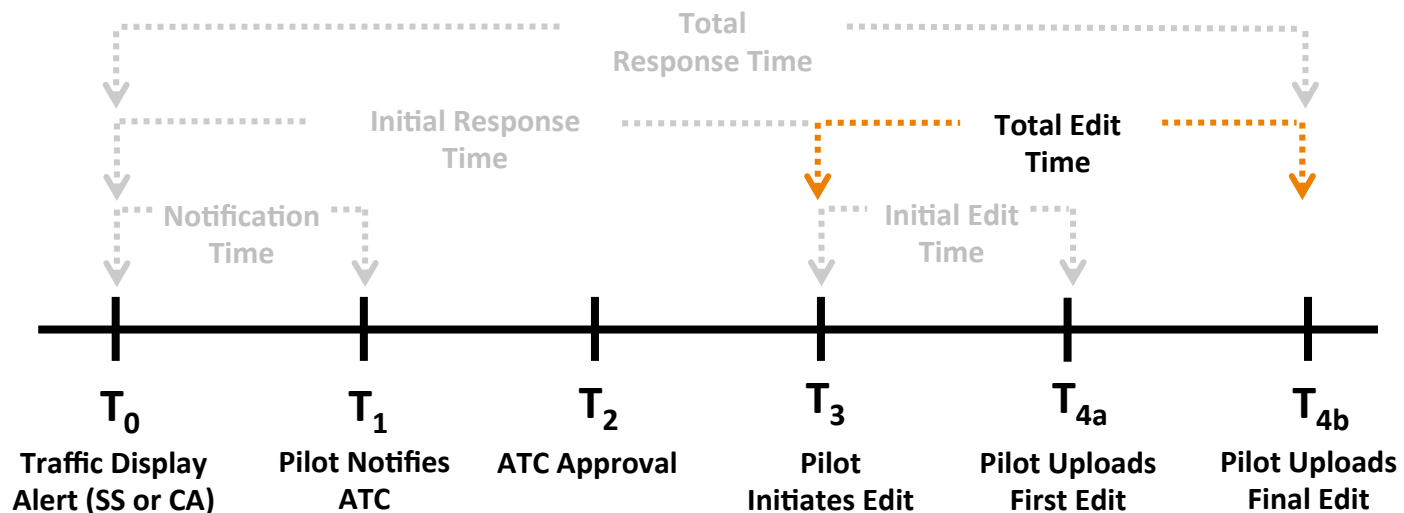
- Near significant effect of Display Location on Initial Response Times ($p = .054$)
 - Pilots took an average of **19.32s** to initiate an edit in response to a SS/CA alert
 - Pilots **5s** faster (23%) in Standalone display conditions
- No other significant main effects or interaction



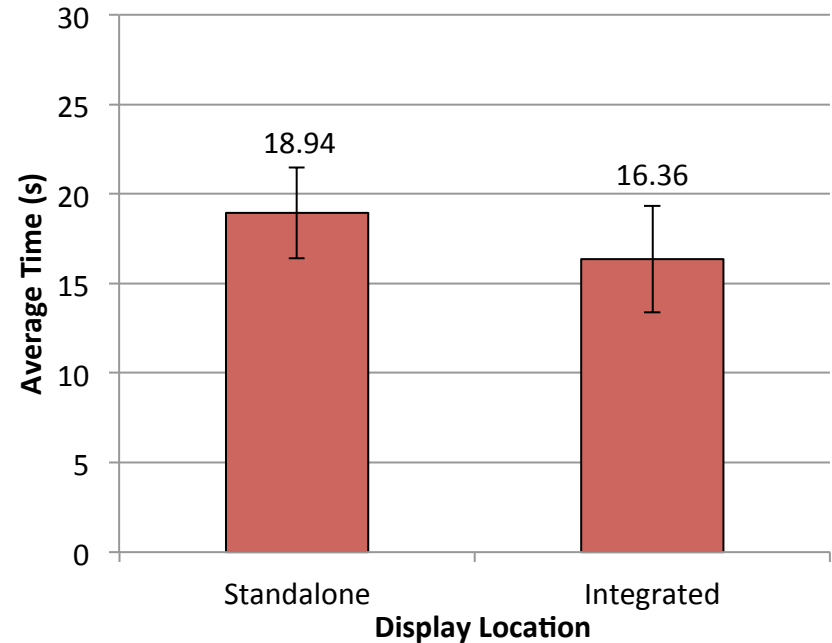
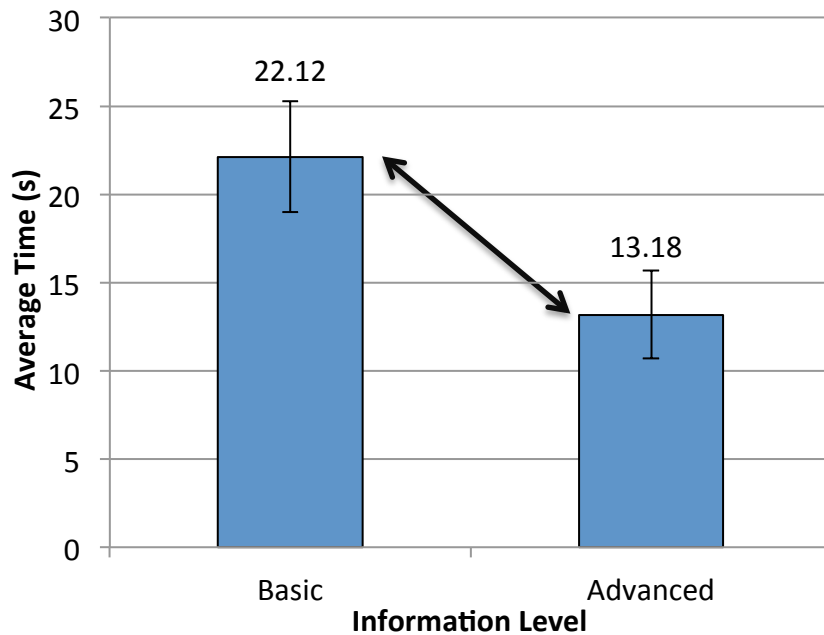
- Measured Response Metrics

- From these timestamps, five metrics were extrapolated:

- Total Response Time* ($T_{4b} - T_0$) – how long it took the pilot to upload an appropriate maneuver following a DAA alert
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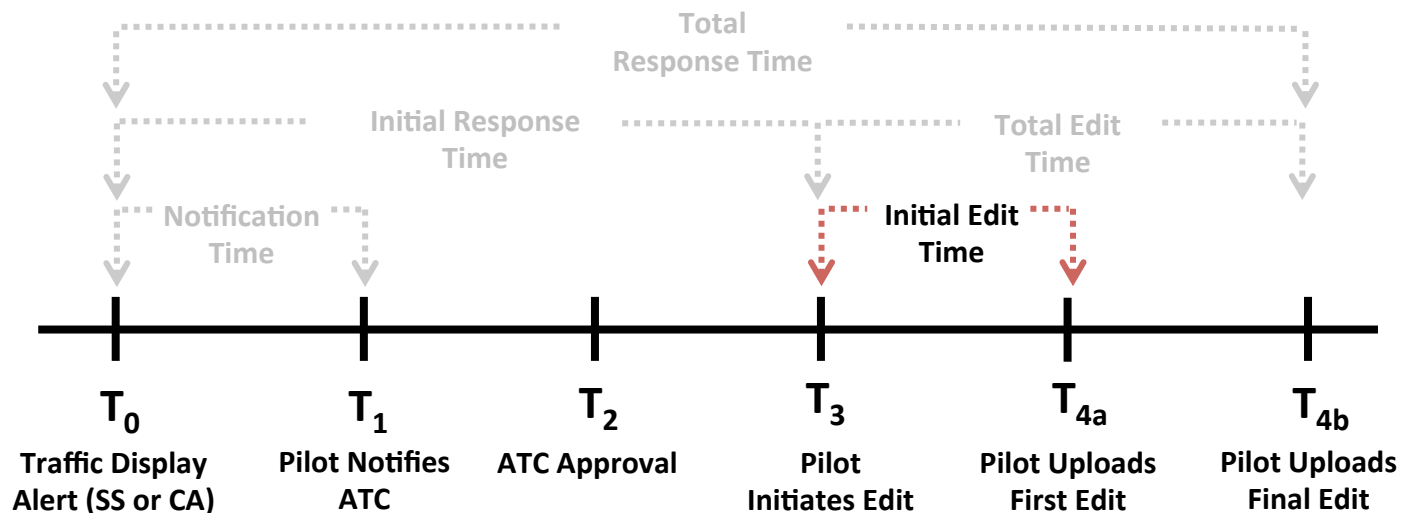
- Total Edit Time
 - Significant main effect of Information Level on Total Edit Times ($p < .01$)
 - Pilots took an average of **17.65s** to complete their final edit in response to SS/CA alerts
 - Pilots **9s** faster (40%) in Advanced display conditions
 - No other significant main effects or interaction



- Measured Response Metrics

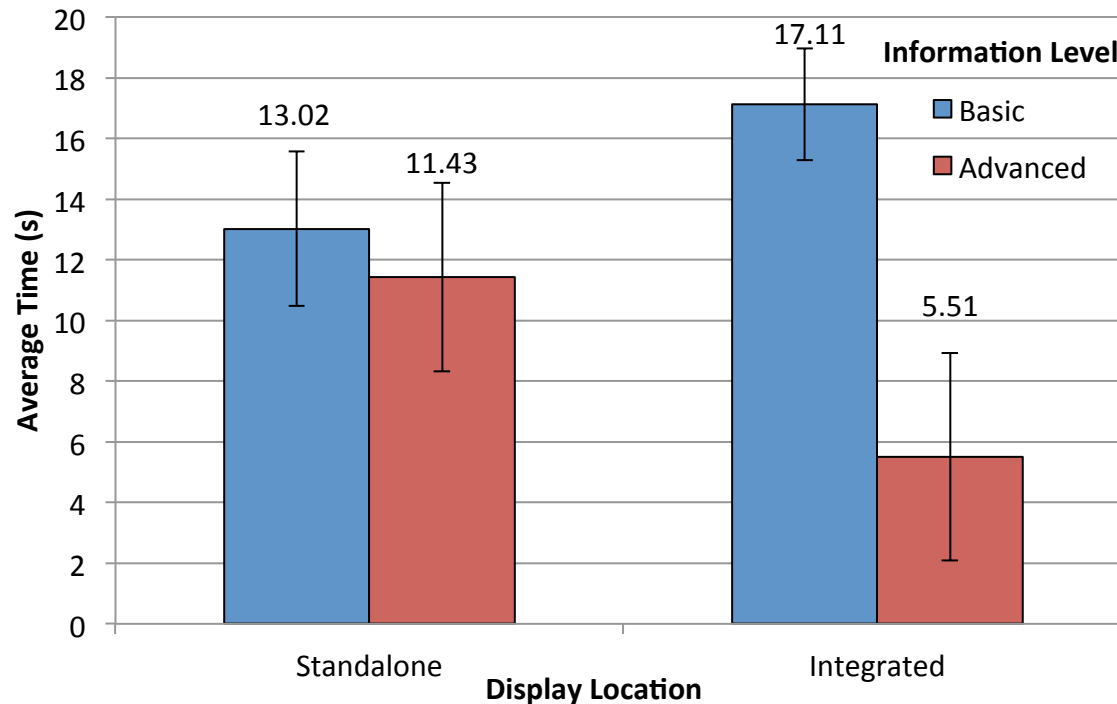
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- Initial Edit Time

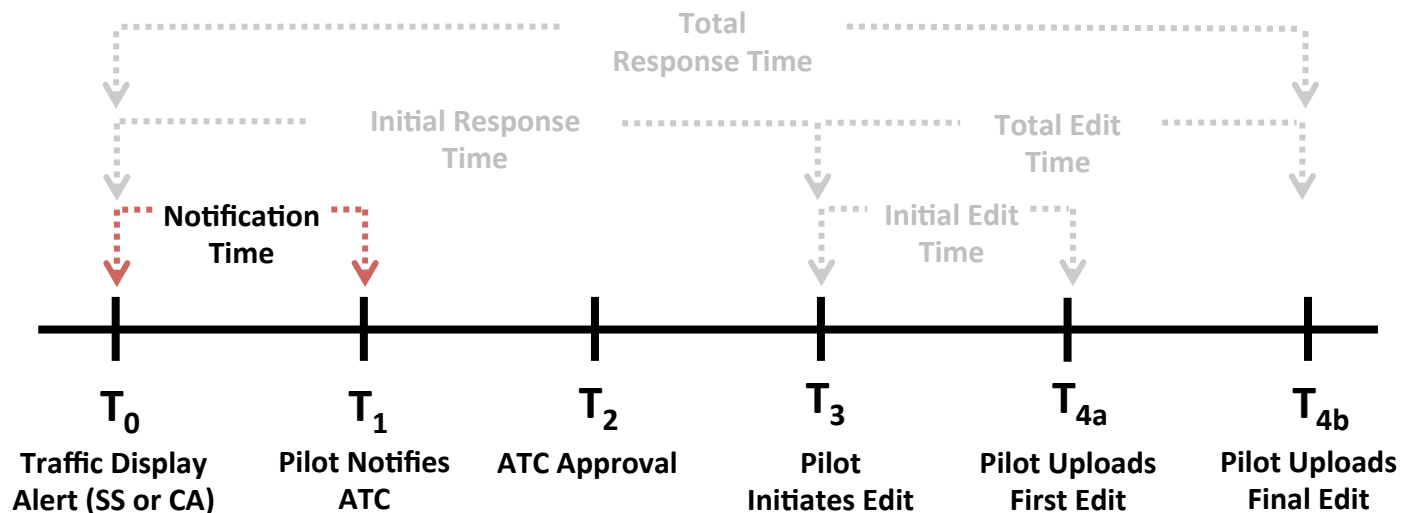
- Significant interaction between Information Level and Display Location on Initial Edit Times ($p < .01$)
 - Pilots took an average of **11.77s** to complete their first edit in response to SS/CA alerts
 - Difference between Basic and Advanced displays in Integrated conditions was **12s** (68%), while only **2.5s** (12%) in Standalone conditions
- Information Level had a significant main effect ($p < .05$), **6.5s** faster in Advanced



- Measured Response Metrics

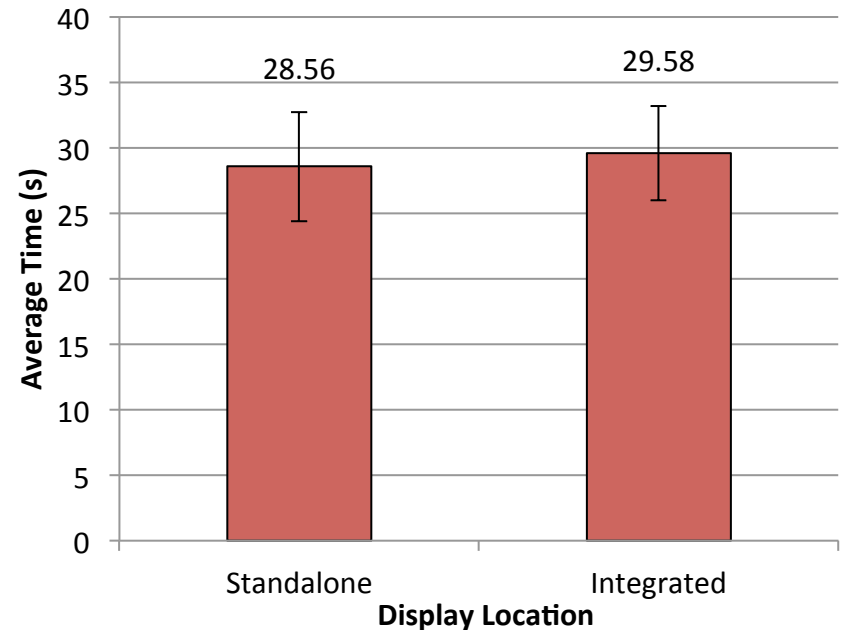
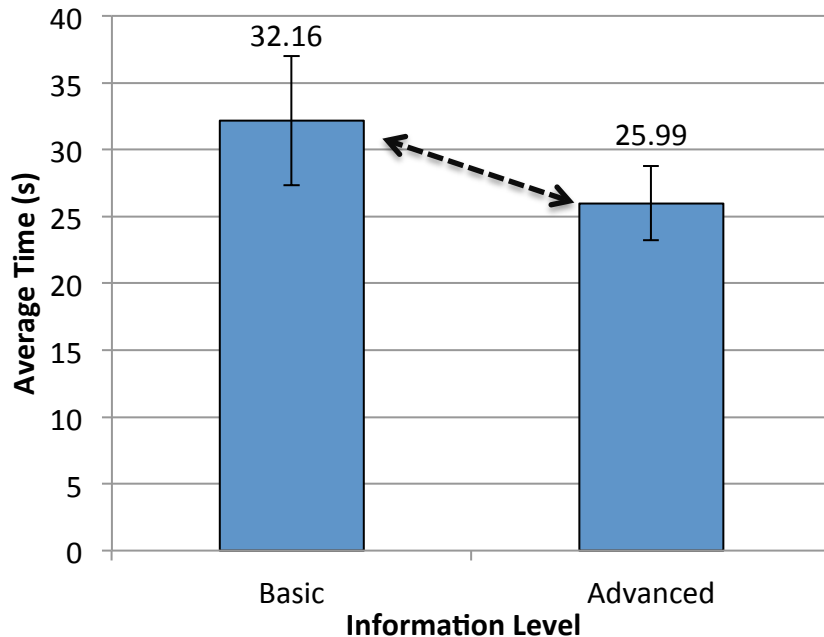
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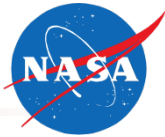
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 - Initial Edit Time* ($T_{4a} - T_3$) – how long it took the pilot to implement an initial maneuver
- Notification Time* ($T_1 - T_0$) – how long it took the pilot to notify ATC following an alert



- Notification Time

- Near main effect of Information Level on Notification Times ($p = .059$)
 - Pilots took an average of **29.07s** to notify ATC of a maneuver in response to a SS/CA alert
 - Pilots **6s** faster (19%) in the Advanced information conditions
- No other significant main effects or interaction





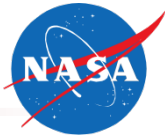
- Summary
 - Advanced Information displays showed advantage in four of five reported metrics
 - Total Response Times 19% shorter in Advanced conditions
 - Total Edit Times 40% shorter in Advanced conditions
 - Initial Edit Times 70% shorter in Advanced Integrated condition than in the Basic Integrated condition
 - Notification Times 20% shorter in Advanced conditions
 - Overall benefit seen for lower Total Response Times was due to a reduction in *how long pilots spent interacting with the display*
 - Not how quickly they got 'in-the-loop' (Information Level did not impact Initial Response Times)
 - Display Location only approached significance in one of the metrics
 - Initial Response Times 23% shorter for Standalone display



- Advanced Information
 - The presence of display guidance (in a variety of forms) reduced the amount of work required of the UAS pilot
 - The Advanced displays unambiguously alerted pilots of which self separation threats were predicted to lose well clear
 - The tools provided the pilot with a pre-determined maneuver, limiting the amount of time they had to spend calculating their own
 - Led to pilots contacting ATC more quickly
 - However it was clear that pilots often initiated edits prior to contacting ATC
 - Roughly 50% of maneuvers occurred without prior ATC approval
- Display Location
 - Did not have a significant impact on pilot performance
 - The lack of *immediate* pilot responses may have mitigated the lack of an effect of display location (Initial Response Times were on the order of **20s**)



- The first in a collection of studies, this sim demonstrated that Information Level, namely the absence or presence of display guidance, can substantially impact pilots' response times
 - Future studies have been conducted that look at different sorts of display guidance to see if certain implementations result in superior performance
- This data is supplemental to other objective metrics – mainly rates of separation violations and pilot feedback – but supports inclusion of display guidance
 - Santiago and Mueller (2015) – found 45% fewer losses of well clear when pilots were provided with display guidance
 - Faster pilot responses is one reason for the finding, among less ambiguous alerting and eliminating the need for the pilot to self-determine a maneuver
 - Quick pilot inputs were especially important in cases of 'pop-up' encounters, where there was a small amount of time before a loss of well clear would appear
 - Monk et al. (2015) – found pilots preferred the Advanced displays
 - Supported more immediate responses
 - While all displays were rated as sufficient, Advanced Integrated was rated as most preferable



- Limitations
 - Cannot necessarily generalize to other GCS
 - Different GCS have different vehicle control inputs
 - There was a high level of integration between the Advanced features and the GCS in the Advanced Integrated condition
 - It is possible to present display guidance with less integration, which may impact pilot performance
 - There were multiple feature changes between the Basic and Advanced conditions
 - Several tools were included, as were several advanced pieces of information, including a new alerting level
- 2 follow-on studies have been submitted to different conferences
 - Both look at different ways to provide display guidance in an integrated fashion
 - HITL data to be validated in flight test environment